UDC 631.4

Eurasian Soil Science, **25** (5), 1993

Translated from
Pochvovedeniye, **24** (12), 1992, 44–52

Radiocarbon Age of Humus of Paleosols and Some Problems of Paleogeography and Geoecology

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Some paleogeographic and geoecological aspects of the radiocarbon method of investigating the humus of paleosols are examined. Examples are the study of the transformation of organic matter of soils in time; paleogeographic reconstructions and climate forecasts; radiocarbon chronology, refinement of geochronological scales, and correlation of natural boundaries of the Pleistocene and Holocene; and chronometry and attempts to predict ecological catastrophes.

Key words: Humus of Paleosols, radiocarbon age, paleogeography, geoecology

The use of the radiocarbon method to study the principles of development of the geosphere for predicting its dynamics and state in the future has great theoretical and applied value. Recently, the method has gone beyond the limits of archaeological and geological investigations and is widely used to reconstruct natural circumstances and make climate forecasts, to study carbon cycles in the atmosphere and biosphere, and to evaluate the contribution of the carbon of soils in its global cycles. No less important is the use of the method in solving ecological problems, especially with respect to technical progress and its active influence on the natural environment (technogenic press), and also in conjunction with the different catastrophic processes of natural and anthropogenic origin.

Experience of using the method for diagnosis and chronometry of natural ecological catastrophes in order to predict them has appeared quite recently [13, 18, 20]. We will discuss some paleogeographic and geoecological aspects of the application of the radiocarbon method: (1) Investigation of the organic matter (OM) of paleosols and its ^{14}C-age; (2) refinement of the geochronological scale and correlation of natural and anthropogenic boundaries of the Pleistocene and Holocene; (3) creation of chronological scales of ecological catastrophes.

At the end of the 1950s at the Institute of Geography of the AS USSR Academician I.P. Gerasimov proposed that the present author investigate the problem of the aging of humus on the

ISSN1064-2293/93/0005-0089
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basis of studying the organic matter of Late Pleistocene paleosols. There were practically no methods of investigating fossil humus, and I.P. Gerasimov turned to Academician I.V. Tyurin for help in developing this problem. Tyurin gave our work great attention and interest; one can say that he was the "godfather" of this trend in our institute and "blessed" the author for studying organic matter of fossil soils, having referred in particular to his 1940 work [16]. We have somewhat modified the method of humus fractionation applied by Tyurin to fossil soils and supplemented it with repeated processing of humins by the Fuks method to understand the nature of the humus of fossil soils: In 1937 [15], Tyurin proposed that the humin fraction of modern soils include humous substances which are formed by means of the aging of humic acid and represented by 70–80 percent with humic acids (HA) and by 20–30 percent with fulvic acids (FA), which was proven experimentally later by Naydenova [11]. The absence of free HA from the OM of buried soils made it possible for us to eliminate the treatment of soils by alkali before decalcification. It also turned out to be inadvisable as applied to buried soils and such treatments as alternative (acid and alkali) treatments and hydrolysis of soils by 1.0 M sulfuric acid. Of the additional treatments, [we] introduced determinations of the optical properties and other physicochemical characteristics of HA of soils of different age. A special place was occupied by investigation of the radiocarbon age of soil OM. All our methodological and theoretical developments on these problems have been sufficiently fully described and published in a series of works and discussed and reported in bibliographies [21]. Here, we will dwell on the most general considerations.

1. **Investigation of OM of paleosols of different age** was carried out by us on the example of chronological series of soils of the Eopleistocene–Late Pleistocene–Holocene, dated by various methods, including radiocarbon.

From the data obtained, it follows that, despite the diagnostic transformation of OM, which appears in a decrease in the carbon content with age and a relative increase in the share of unhydrolyzable residue, an increase in the content of calcium humates and the degree of oxidation of the HA, a decrease in the aliphatic groups, etc., *the main properties of its components and their relationships, which are characteristic of soils of a certain type, are preserved*. These indicators can be used to judge the past course of at least the forest or steppe processes of pedogenesis, and also their hydromorphic or automorphic origin. Thus these indicators may serve for diagnosis of the soil types and for paleosol reconstructions. Concerning the HA of soils, analysis of the physicochemical properties only confirmed their specific soil nature, which makes it possible to identify them as HA with the characteristic content of hydrogen, nitrogen, carbon, and the atomic ratios H:C and O:C, which differ little from the HA of modern soils. However, we may note the higher degree of oxidation, the decrease in the share of aliphatic compounds of the amino acid and polysaccharide type with the age of the HA, which is confirmed by data of infrared spectrophotometry. The overall set of absorption bands is typical for HA of both ancient and modern soils, although in the latter it is more diverse. HA of ancient soils have practically no CH_2- or CH_3-groups which characterize the aliphatic portion of the HA molecule, which is evidently less resistant to diagenesis.

Thus, with an increase in the age of the fossil soils, a decrease in the share of aliphatic chains and an increase in the share of cyclically polymerized carbon groups are observed, and the degree of condensation and oxidation of the HA grows; there occurs dehydration and loss of the CH_3-groups, and the number of carboxyl and phenol hydroxyl groups increases; the content of

Table 1

Radiocarbon Age of Humus of Bryansk Fossil Soil and Its Analogues on the Russian Plain and in Western Siberia

Sampling site	Cross section no., soil	Depth, m	Dated fraction	Laboratory number of IG AS	Age, years
Arapovichi, Chernigov Oblast	Bryansk soil	7.9–8.0	HA-2	46	24000±300
The same		The same	HA-2+HA-3	55	31500±1400
Mezin, Chernigov Oblast	3–60, Bryansk soil	3.2	HA-2	88	24300±370
					24210±270
Novokhopersk, Voronezh Oblast	1–71	6.0	The same	87	22870±220
Novokhopersk, Voronezh Oblast	1–71	6.0	The same	9-MGU-344	32550±700
Basov Kut, Rovno	Dubnovskiy soil	9.0	The same	74	28400±850
Krasnoselka, Khmel'nitskaya Oblast	The same	The same	The same	170	24400±1000
Fat'yanovka, Ryazan Oblast	1–72–4	4.5	The same	197	22300±1250
Mezherichi, Cherkassy Oblast	Bryansk soil	3.9	The same	337	24150±740
Zheleznogorsk, Kursk Oblast	The same	4.0	The same	338	24180±900
Mramornyy quarry, Novosibirsk Oblast	1–76, Upper Iskitim soil	3.8	HA-2	167	26300±700
	Lower Iskitim soil	4.0–4.5	HA-2+HA-3	168	29000±450
Lozhok, Novosibirsk Oblast	2–76	1.5	The same	169	30000±1000
Inya, Novosibirsk Oblast	4-76	2.6	The same	199	24300±380
Tiraspol', Moldova	2–85, Bryansk soil	2.0	HA-2	768	29240±2260

carbohydrates diminishes; the yield of benzene-polycarboxylic acids increases significantly. The molecular-mass distribution shows a decrease in the share of high-molecular and an increase in the share of low-molecular fractions of soils with the increase in age. Only a portion of the properties of HA may serve for diagnosis and paleoreconstructions, which are one of the constituents of the geoecological monitoring and predictions of the state of the biosphere [22].

During the last decade, significant successes have been achieved in the application of the radiocarbon method for investigating OM and the age of fossil soils. Dates for fossil soils define the upper age limit of their past existence. In fossil soil, we deal with carbon which is part of the "conserved" humous substances found under the conditions of burial in a series of sedimentary rocks and isolated both from the biological cycle and also from isotope exchange with atmospheric carbon dioxide. This is a practically "closed" system with respect to carbon exchange or "open-closed" if we are thinking about its past existence on the surface. The "dating" fractions in the OM of paleosols are the HA which are stably bound with the mineral portion of the soil. In different laboratories, benzene was synthesized from the carbon of preparations of fossil soil HA for scintillation count. Different fractions of HA and of the humus horizon of the Bryansk fossil soil from one section [21] were dated as methodological and control determinations at these laboratories. As our investigations showed, the radiocarbon age of humus of the Bryansk fossil soil did not depend either on the method of preliminary preparation of the sample or on the count of the activity of the radiocarbon or on the dated fraction (Table 1). This made it possible to modify the preparation method and reduce it to obtaining the sum of HA fractions 2 and 3. The objects of the radiocarbon investigation consisted of paleosols of the Upper Pleistocene and Holocene, which have been studied in detail by Velichko and Morozova [5], Velichko et al. [3], Morozova [10], Aleksandrovskiy [1], and others.

2. **Refinement of geochronological scale based on correlation of natural boundaries of the Holocene and Upper Pleistocene.** Radiocarbon data were confirmed by the following reference-point [3] horizons of paleosols of the Late Cenozoic: end of the Mikulinian Interglacial-Krutitskiy Phase of loess-soil complex with trans-boundary age of > 40–55 thousand years ago; Valday Interstadial-Bryansk fossil soil (32–22 thousand years ago); Late glacial soil horizons (17–12 thousand years ago); Holocene paleosol (from 10 thousand years ago to the present).

Investigation of the geography of the ^{14}C-age of fossil soils of the Bryansk Interstadial and its equivalents made it possible to compare the major events of the last glacial epochs in Europe and North America in time. The synchronicity of these events appeared in the formation of soil horizons of the same age which are stratigraphically persistent in the Northern Hemisphere.

We obtained a large mass of data and systematized the data in the literature for different geographic groups of soils of the *Bryansk Interstadial*. Radiocarbon analysis showed that there are practically no differences in the age interval of these groups. Some differences in the dates for this horizon reflect, on one hand, the dissimilar preservation of the soil profile and the confinement of the dated material to different time segments within the given interval, and, on the other hand, regional differences in the character and rates of pedogenesis in the Bryansk time (Table 1).

Based on ^{14}C-dating of the OM of the Upper Pleistocene soils of the southwestern Russian plain, we, for the first time, isolated the horizon of the so-called Allerjod soil with an age of 10–12 thousand years, analogues of which have been described in the southern area of western Siberia

and in central Europe. The use of the sequential series of ^{14}C-dates for loess-soil series along with determination of the age of individual horizons allowed A.A. Velichko et al. [5] to establish the chronology of natural climate meso-scale fluctuations for the Late Pleistocene, and also to carry out a differentiated evaluation of the accumulation of loesses.

Correlation of natural boundaries of the Holocene was based on the investigations of the radiocarbon age and chronology of paleosols, stages of their Holocene evolution in the Baltic region, in the center of European Russia, and in the Eastern MPR. The course of climate changes in these regions differs, and a linear climate correlation is obviously unacceptable. However, in the opinion of N.A. Khotinskiy [17], this does not obstruct correlation of the climate boundaries of the Holocene according to ^{14}C-dates, each of which turns out to be synchronous on enormous territories (Fig. 1).

Data on ^{14}C-dating, morphology, composition, and properties of OM of paleosols of the northwestern European territory of Russia in a complex with other methods allowed the conduct of paleosol and paleoclimate reconstructions and reconsideration of some views on the genesis and evolution of modern Sod-Podzolic soils of sands [2]. The following stages of Holocene evolution have been identified: soil of the Lower Sub-Boreal (SB), well differentiated, was formed in a humid, warm climate, then in the middle of the SB eolian processes were activated and deflation of sands, which was a consequence of the aridity of the climate; Sod-Podzolic soil was formed, and as a result of the strengthening of anthropogenic pressure, clearing of forests, and deflation in the Sub-Atlantic (SA) period, this soil evolved into Podzolic soil, which develops under conditions of climate cooling (strengthening of humidity and cooling).

In the center of European Russia, on loams, in the development of paleosols, three chronological stages are noted which correspond to the succession of types of pedogenesis and bioclimate circumstances (according to palynological data). This is fixed by the intensity of the processes of humus formation and the specifics of the humus profile of the appropriate radiocarbon age. Sod-Meadow alluvial hydromorphic permafrost-gley soils of the Boreal (BO) were replaced by thick differentiated soils of the warmer and humid Atlantic (AT) time, with Meadow soils with a dark-colored humus horizon. And under conditions of cooling and increasing of the humidity in the SB, there is a degradation of the dark-colored horizon and the soils evolve into Meadow-Forest-Steppe soils [4, 5].

In the east of the Mongolian People's Republic (MPR), the character of the paleosols, properties, and ^{14}C-age of the humus, and also abundant finds of tools (mesolite, bronze, iron) [7] showed that, in their development, the soils were related to eolian accumulation. The change in the soil types on the time scale allowed outlining of the paleogeographic changes of the region from humid, warm conditions of the AT to cold, arid natural circumstances of the SB, and sharply continental semiarid conditions of the SA. Our determination of the ^{14}C-age of the paleosols of eolian forms of the southern area of eastern Mongolia agrees with the ^{14}C-age of bottom deposits of lakes of the MPR [6] and with the age of analogous deposits of temperate latitudes of China [8] (Table 2).

Thus the following large climate boundaries have been identified according to ^{14}C-dates for paleosols of the northwest, center of European Russia, and eastern Mongolia: BO-2, AT-3, SB-3, SA-3 (Fig. 2).

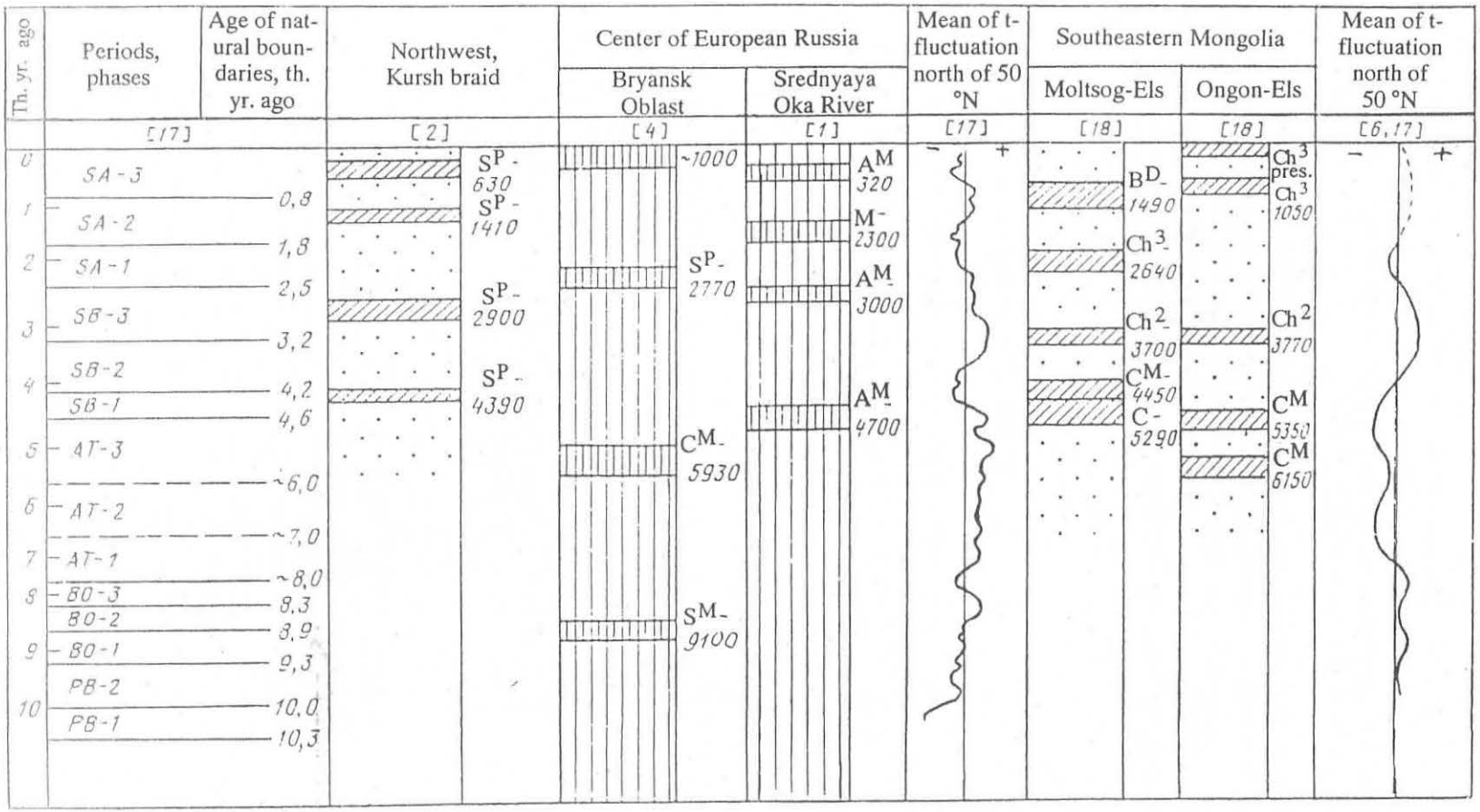

Fig. 1. Radiocarbon chronology of paleosols and correlation of natural boundaries of Holocene (according to ^{14}C-dates, yr. ago). Abbreviations: Phases of periods of Holocene: (SA) Sub-Atlantic, (SB) Sub-Boreal, (AT) Atlantic, (BO) Boreal, (PB) Pre-Boreal. (1) Sandy deposits, (2) humus horizon of sandy paleosol, (3) loams, (4) humus horizon of loamy paleosol, (5) ancient mole runs. Soils: (S^P) Sod-Podzolic, (S^M) Sod-Meadow, (C) Chernozem-like, (Ch^M) Chernozem-Meadow, (M) Meadow, (A) Alluvial, (A^M) Alluvial Meadow, (Ch^2) Chestnut, (CH^3) Dark Chestnut, (B^D) Brown Desert.

Table 2

Composition and Age of Humus of Paleosols of Sandy Massifs in Eastern Mongolia*

Cross section	Depth, m	C_{tot}, %	C_{HA}/C_{FA}	IGAS Laboratory No.	^{14}C-age
Ch-15–20	90–100	0,88	1,06	560	1050±50
	120–130	0,26	0,26	593	3770±130
	180–180	1,04	0,89	558	5350±130
	230–240	0,55	1,50	557	6150±70
Ch-16–83	0–10	1,11	0,80	563	Present
	50–60	0,43	0,28	561	3680±50
Ch-97–84	10–12			620	1490±170
	60–70			619	2640±220
	230–240			618	3730±550
	250–260			617	4830±150
	280–290			523	5290±300

* Determinations of humus composition made at the chemical laboratory of the Institute of Geology of the Russian Academy of Sciences by Ye. N. Subbotina.

3. **Investigation of chronology and periodicity of ecological nature catastrophes.** As a result of the investigation of the radiocarbon chronology and periodicity of ecological catastrophes related to hurricanes, volcanic activity, and earthquakes, the following data were obtained.

A. Large 500- and 1000-year cycles are identified in the change in activity of eolian processes in eastern Mongolia which are related to hurricane activity; these cycles have also been noted by Chinese scholars on the territory of the PRC [9]. Within these cycles on the territory of the MPR, a more detailed cyclicity is noted: 11–12-year cycles of hurricane activity have been identified. Based on analyses of OM and ^{14}C-dates for paleosols buried in sand dunes of the plains of eastern Mongolia and the genesis of eolian relationships, it can be concluded that the periods of development of paleosols were characterized by the decline of eolian processes, whereas the periods of formation of eolian sands which separate them were characterized by the strengthening of deflation and accordingly by eolian accumulation [18]. The shifting eolian sands buried the soils repeatedly (at least five times during the Middle and Late Holocene).

In the dynamics of eolian processes, two mechanisms are fairly clearly identified: constant slow shifting with wind speeds of 5–15 m/s and hurricane gusts of loose material to beyond the limits of eastern Mongolia by winds with speeds exceeding 20 m/s in the high layers of the atmosphere. Hurricanes are a typical phenomenon for these localities. A dynamic model of the distant eolian transport of silt may be the hurricane of 1980, which left serious disturbances in natural environment behind it in eastern Mongolia and caused sand and dust storms and the transport and deposition of a significant amount of silt even in China [8].

The definite cycles of activation of eolian processes (including those of a hurricane character) in eastern Mongolia presented in a report to the Ecology Committee of the Mongolian

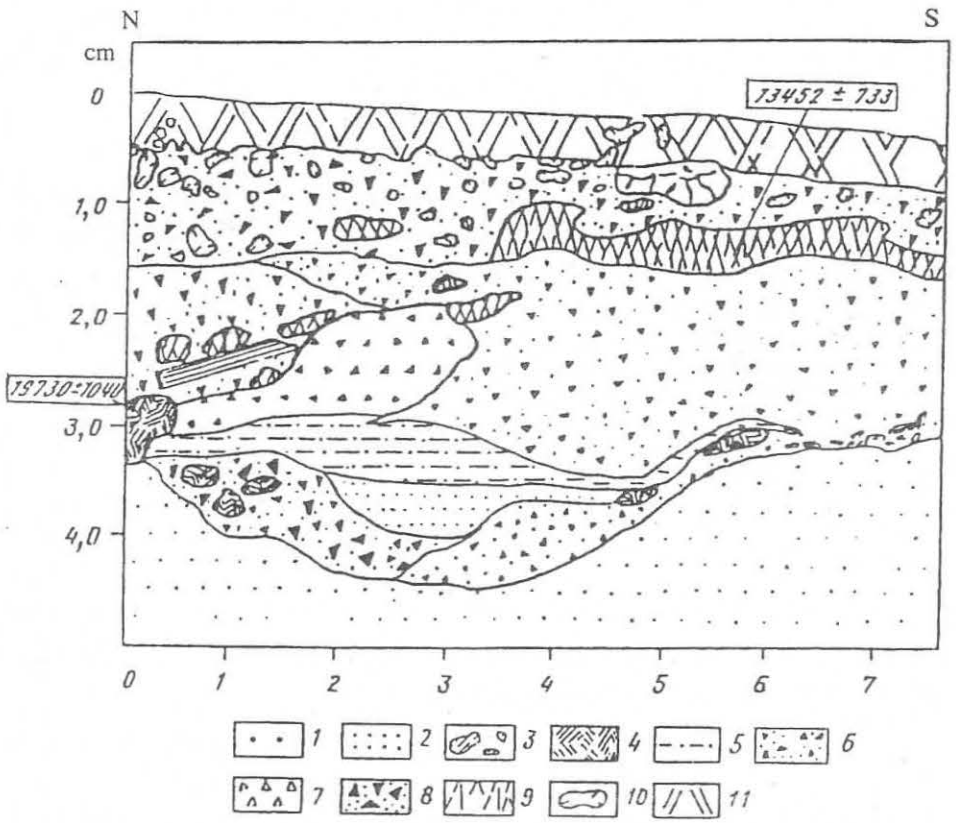

Fig. 2. Section of pit 996 (east wall) in upper part of western slope of Aktash Range. (1) Sands of Upper Neogene, (2) thin stratified sands, (3) clayey pellets, (4) fragment of older Pleistocene paleosol, (5) fragment of younger Upper, *in situ*, Upper Pleistocene paleosol, (6) fine-grained stratified material, (7) small-fragment granulated material, (8) loose, porous detrital mass (fill), (9) dense, heterogeneous detrital-rubbly mass, (10) larger fragments, (11) modern soil.

Academy of Sciences in 1990 may be considered in conducting protective anti-hurricane measures in these regions.

B. The radiocarbon age of wood buried by tephra of the Pektusan volcano (North Korea) was analyzed, and the cycles of volcanic activity which led to catastrophic consequences for the environment and humans were determined. The chronological series from 16 events (eruptions) was supplemented by a series of ^{14}C-datings, on whose basis the cycles of repetition of volcanic activity (macro- and microcycles) are identified: 10–30, 50–70, and 90–196 years. The identification of these cycles is the basis for prediction.

C. The radiocarbon age of paleosols buried as a result of paleoseismic dislocations related to earthquakes is investigated.

The possibility of determining the age of past earthquakes is related to the fact that they are accompanied by secondary disturbances of the relief and surface deposits (including soils). Strong earthquakes are often accompanied by such seismogravity formations as cave-ins, landslides, mud flows, breakaways, and rockfalls. The bodies of these formations, especially in the peripheral areas, lie on developed soil cover of slopes and bottom areas of river valleys, and in individual cases they overlap the culture layers of archaeological objects; sometimes archaeological encampments arise on these formations or are related to them. The use of the ^{14}C-method of determining the age of seismic events along with historical data on earthquakes allows refinement of the seismic statistics and shift to an evaluation of the frequency of earthquakes [12]. Thus, with the help of radiocarbon dating of fragments of paleosols related to paleoseismic dislocations in the region of the Aktash range of the Kerch Peninsula, large catastrophic events have been identified which are related to historical earthquakes, which was also confirmed by morphological descriptions of the corresponding horizons of disturbed soil profiles (Fig. 2). Thus we have noted at least six strong seismic events during the past ~20 thousand years [14] which can be arranged into a chronological series beginning with the end of the Pleistocene, in the Holocene, and in the present: (1) > 490 years ago (1390–1530—14th century A.D.; (2) > 1610 years ago (earlier than 340 A.D.)(; (3) > 2100 years ago (2d–1st centuries B.C. to 63 B.C.); (4) > 6500 years ago (6–7 thousand years ago); (5) > 13,450 years (14–13 thousand years ago); (6) > 19,130 years ago (20–18 thousand years ago).

Some earthquakes are diagnosed both according to archaeological data and also according to ^{14}C-data for paleoseismic dislocations (according to fragments of paleosols), for example, the historic earthquake of 63 B.C. Thus ^{14}C-dating of paleosols and the investigation of paleoseismic dislocations reflected in their profiles and in the character of the series enclosing them made it possible to do a time study of major seismic events of the Pleistocene and Holocene, and some results of our investigations on the Kerch Peninsula were used in a decision of a government commission on evaluating the ecological situation in the region of construction of the Crimean Atomic PP and conservation of the latter.

The use of the radiocarbon method for dating and timekeeping of catastrophic phenomena in nature has great value in investigating their periodicity (cyclicity) both for monitoring and also for predicting the frequency of ecological catastrophes, and the means for the possibility of predicting them or at least taking the appropriate nature-conservation measures.

Bibliography

1. Aleksandrovskiy, A.L. 1983. *Evolyutsiya pochv Vostochno-Yevropeyskoy ravniny v golotsene* (Evolution of soils of the East European plain in the Holocene). Moscow, Nauka.
2. Aleksandrovskiy, A.L., and O.A. Chichagova. 1980. Radiocarbon chronology of Holocene paleosols. In *Geokhronologiya chetvertichnogo perioda* (Geochronology of the Quaternary Period). Moscow, Nauka, 82–90.
3. Velichko, A.A., A.K. Markova, T.D. Morozova, and V.P. Udartsev. 1984. The problem of geochronology and correlation of loesses and fossil soils of Eastern Europe. *Izv. AN SSSR. Ser. Geogr.*, No. 6, 5–19.
4. Velichko, A.A., T.D. Morozova, O.A. Chichagova, and A.S. Isayeva-Petrova. 1984. Application of paleogeographic methods of investigation in studying Holocene soils. In *Istoriya*

razvitiya pochv SSSR v golotsene. Tez. dokl. Vsesoyuz. konf. (History of development of soils of the USSR in the Holocene. Abstracts of All-Union Conference). Pushchino, ONTI NTsBI AN SSSR, 41–42.

5. Velichko, A.A., and T.D. Morozova. 1986. Paleogeographic foundations of the history of formation of modern soil cover. In *Vozrast i evolyutsiya pochv* (Age and evolution of soils). Pushchino, 22–36.
6. Vipper, P.B., I.I. Dorofeyuk, Ye.P. Metel'tseva, and V.T. Sokolovskaya. 1981. Holocene paleogeography of central Mongolia. *Izv. AN SSSR. Ser. biol.*, **30** (1), 71–74.
7. Dordzh, D. 1971. *Neolit Vostochnoy Mongolii* (The Neolithic of eastern Mongolia). Ulan-Bator, Izd-vo AN MPR.
8. Dunshen, Lyu. 1986. Achievements in studying the Quaternary Period of China. In *Issledovaniya chetvertichnogo perioda. Izbr. dokl. XI Kongressa INKVA* (Investigations of the Quaternary Period. Selected reports of the 11th Congress of INQUA). Moscow, Nauka, 53–64.
9. Dunshe, Lyu, Dun Guanzhun, and An Chzhishen. 1984. Natural situation of desert and loess regions of China in the Quaternary Period. In *Chetvertichnaya geologiya i geomorfologiya. Dokl. 27–go Meshdunarod. geol. kongr. Sektsiya C. 03* (Quaternary geology and morphology. Reports of the 27th International Geological Congress. Section C. 03). Moscow, Nauka, Vol. 3, 82–86.
10. Morozova, T.D. 1981. *Razvitiye pochvennogo pokrova Yevropy v pozdnem pleystotsene* (Development of soil cover of Europe in the Late Pleistocene). Moscow, Nauka.
11. Naydenova, O.A. 1951. The problem of the nature of humin of soil humus. *Uch. zap. MGU, Ser. biol. nauk*, No. 140 (27), 69–85.
12. Nikonov, A.A., A.V. Vakov, and I.P. Veselov. 1983. Paleoseismic dislocations and paleoearthquakes. In *Seysmotektonika i zemletryaseniya zony sblizheniya Pamira i Tyan'-Shanya* (Seismotectonics and earthquakes of the Pami–Tien Shan juncture zone). Moscow, Nauka, 100–104.
13. Nikonov, A.A., O.A. Chichagova, A.Ye. Cherkinskiy, and M.A. Petrenko. 1990. New approaches to stratigraphic separation and paleoecological reconstructions of slope deposits with the help of ^{14}C-dating of buried soils. In *Chetvertichnyy period: metody issledovaniya, stratigrafiya i ekologiya. Tez. VII Vsesoyuz. soveshch.* (The Quaternary Period: Methods of investigation, stratigraphy, and ecology. Abstracts of 7th All-Union Conference). Tallinn, Vol. 3, 20–22.
14. Nikonov, A.A., O.A. Chichagova, and A.Ye. Cherkinskiy. 1992. Radiocarbon dating of soils for diagnosis of slope dislocations (by example of the site of the Crimean Atomic PP on the Kerch Peninsula). *Geokhronologiya chetvertichnogo perioda* (Geochronology of the Quaternary Period). Moscow, Nauka, 80–90.
15. Tyurin, I.V. 1937. *Organicheskoye veshchestvo pochvy i yego rol' v pochvoobrazovanii i plodorodii* (Organic matter of soil and its role in pedogenesis and fertility). Moscow-Leningrad, Sel'khozgiz.
16. Tyurin, I.V., and Ye.I. Tyurina. 1940. Composition of humus in fossil soils. *Pochvovedeniye*, No. 2.
17. Khotinskiy, N.A. 1987. Radiocarbon chronology and correlation of natural boundaries of the Holocene. In *Novyye dannyye po geokhronologii chetvertichnogo perioda* (New data on geochronology of the Quaternary Period). Moscow, Nauka, 39–45.
18. Chichagov, V.P., and O.A. Chichagova. 1987. Radiocarbon chronology of paleosols and history of formation of eolian relief of eastern Mongolia in the Holocene. In *Novyye dan-*

nyye po geokhronologii chetvertichnogo perioda (New data on geochronology of the Quaternary Period). Moscow, Nauka, 61–67.

19. Chichagov, V.P., Rim Kvon Muk, A.Ye. Cherkinskiy, and O.A. Chichagova. 1989. Radiocarbon age of trees buried by tephra on the Pektusan volcano in North Korea. *Dokl. AN SSSR*, **306** (1), 169–172.
20. Chichagov, V.P., A.Ye. Cherkinskiy, and O.A. Chichagova. 1990. Radiocarbon chronology of the appearance of modern volcanism and time of major ecological catastrophe in the Asian Far East. In *Tez. vsesoyuz. soveshch. Geokhronologiya chetvertichnogo perioda* (Abstracts of All-Union Conference. Geochronology of the Quaternary Period). Moscow.
21. Chichagova, O.A. 1985. *Radiouglerodnoye datirovaniye gumusa pochv* (Radiocarbon dating of soil humus). Moscow, Nauka.
22. Chichagova, O.A., and T.I. Tarasova. 1982. *Svoystva raznovozrastnykh guminovykh veshchestv*. (Properties of humin substances of different ages). *Pochvovedeniye*, No. 1, 94–99.

Received 15 June 1991